Texture Characteristics of Chips Produced by Hot Sand Frying

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Texture Characteristics of Chips Produced by Hot Sand Frying

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Abstract. Frying can be performed both with oil and without oil. Hot sand frying is one of the methods of frying that does not use oil. Chips are often produced using this method, where heating takes place at high temperatures. During frying, heat transfers from the hot sand to the chips, causing the texture of the chips changes from soft to hard and crispy, followed by surface hardening. Unfortunately, there have not been many published papers focusing on this topic. Therefore, this study was aimed to study the changes in the texture of chips as the effect of hot sand frying. Chips are high in carbohydrate, and they were fried at 120-160ºC for 10-25 s in a frying cylinder rotated at 35 rpm. Chemical and physical characteristics of the chips sample were analyzed before and after the frying process. Results show that there changes in texture characteristics of the chips during frying. It affected the hardness and crispiness of the chips due to the loss of moisture and changes in the carbohydrate. Thus, the texture changes model developed could be used to predict changes in the chips texture from hard to crispy, as a function of water evaporation and a decrease of carbohydrate content in the chips.

Keywords: characteristics, texture, hardness, crispiness, chips, hot sand frying

1. Introduction

Hot sand frying is a frying method that does not involve oil. During frying, heat is transferred from the sand. Direct contact occurs between the heating plate with the sand or any other solid material, while in deep-fat frying, heating occurs from direct contact between the heating plate and cooking oil as the heat transfer media. Several advantages of hot sand frying compared to deep-fat frying are the lack of frying oil that gets absorbed into the product thus it does not get rancid easily, the less expensive cost of sand, and if the product loses its texture, a simple solution of drying it under sunlight at 35-45ºC.

Moreover, the lack of frying oil absorbed into the product is also beneficial regarding the health aspect. Despite all the benefits, this method also has a disadvantage, which is the lack of savory flavor that usually comes from the use of frying oil. Hot sand frying, unfortunately, has not had standards, yet thus a good control of the process needs to be developed in order to produce products that fulfill the quality as demanded by consumers. More comprehensive researches are needed to be developed by considering the characteristics and conditions of the ingredients used. These considerations should then be taken into account in developing a model of heat and mass transfers simultaneously as well as the changes in texture (soft-hard) that occur during the hot sand frying process.

During hot sand frying process, heat transfer takes place from the sand to the product, and mass transfer in the form of water or moisture occurs from the internal part of the product to the surface (or

called evaporation), which cause physical and chemical changes of the product. Physical changes involve faster frying, crispiness, and changes in porosity and texture. Meanwhile, chemical changes are for example moisture evaporation, starch gelatinization, and protein denaturation. There have been many approaches taken to explain the condition and changes that take place during drying of food products such as a study on starchy food performed by Takeoka [1] who developed a model to describe the phenomena of heating, loss of moisture content, and oil content. Development of a mathematical model of the changes that might happen during drying of food was done many researchers [2][3][4]. Their results managed to explain that frying could change the product structure, shrinkage, expansion, and changes in texture and chemical characteristics. Moreover, Yamsaengsung & Moreira [3] also developed an empirical model to show the change of volume in tortilla chips during frying. Their results showed that tortilla chips experienced shrinking and expansion due to the expansion of the gas bubbles contained in the chips. Other researchers developed another model to explain the heat and mass transfers in the frying of paper, where loss of bound water was considered to be the primary cause of shrinking in the product. However, it has not been explained the effect of simultaneous heat and mass transfers during frying as well as the observed changes in the textures based on the dimension of the product [5][6]. Therefore the primary objective of this study was to observe the changes in characteristics and crispiness of the product during hot sand frying. Meanwhile, the specific objectives of the study were to predict physical and chemical during hot sand frying with the sand as the heating transfer thus the results could hopefully help to develop chips with better texture quality like hardness and crispiness in order to fulfill the demand from the consumers for the right products with low health risks.

The phenomenon of changes in the characteristics hardness and crispiness (soft-hard) during hot sand frying of starchy food has not been published widely. Other than flavor hardness and crispiness are also quality indicators of chips. Understanding this topic could help to design quality of chips products made from high carbohydrate and starchy ingredients that are common in traditional Indonesian foods. It is expected that this understanding will bring chips with better texture and good flavor with low oil content. Therefore, hot sand frying can be expected to be a technology of interest to be explored more in the future.

2. Research Methodology

2.1. Types of sand

Types of sand used as the heat transfer media were divided into two: first was mountain sand, which was obtained from sand mines; it had rough granules and relatively less hard. Usually, this type of sand contains pozzolan that can be mixed with lime and water; it will harden to create a solid mass. The second type of the sand was river sand, which was collected from the river bottom that was formed from erosion of the rocks and it had granules with the size of 0.063-5 mm.

2.2. Changes in hardness and crispiness

The texture of a product depends on the how compact the particles that form it as well as on the size of other particles [7]. Texture can be measured objectively from the functions of time, mass, and distance, and it can also be experienced through touch. Changes of texture during frying had been modeled by Pedreschi & Mayano [8] by observing the texture of chips during frying. According to Szczesniak [9], an assessment of the texture of food, two methods can be used: instrumental measurement and sensory testing (organoleptic). Instrumental measurement used laboratory instruments, while sensory testing depended on the human senses. Changes in texture regarding hardness and crispiness were affected by evaporation of the free water as well as reduction of starch content in the solid material. When moisture content in the solid material was not constant yet, an increase of hardness and crispiness was still low; however, when moisture content in the solid materials started to get constant, there is a rapid increased in hardness and crispiness that continues till

the end of the frying process. However, those researchers had not developed the mathematical model yet that can be used to predict the changes in hardness and crispiness during the frying process.

2.3. An empirical equation for a mathematic model of changes in hardness and crispiness

In this study, an empirical equation was developed to describe the changes in the texture of chips. Changes in texture were hypothesized to be caused by the changes in evaporated moisture content as well as in carbohydrate content whose granules expanded during hot sand frying. Therefore, the changes in the texture of the chips could be explained by the following empirical equation:

$$T_{\sigma(Ca,\ Ckb)} = f(C_a,\ C_{kb}) \quad (1)$$

2.4. Hot sand frying

The sample was fried in hot sand at 120, 140, and 160ºC, for 10, 15, 20 and 25 s, with the cylinder rotated at 35 rpm.

2.5. Observation of frying temperature

The temperature of the sand and the sample during frying was measured using type K thermocouple that was equipped with a data logger with the accuracy of ± 1ºC. The thermocouple was located at several positions in the sand and the sample. The observation was performed at two parts: heat transfer and changes in the texture of the chips during frying.

2.6. Data analysis

Data collected in the study was analyzed statistically using Microsoft Excel to find the correlation between observational data and results from a simulation model. The data that were used for the correlation analysis included temperature increase, a decrease of moisture content, changes in carbohydrate and protein content during the frying process using hot sand as the heat transfer media.

3. Results and Discussion

3.1. Heat and mass transfer during hot sand frying of starchy food

Changes of the temperature of the chips during frying were observed using data logger. Data were collected from the hot sand that was used as the heat transfer media as well as from the chips. Figure 1a shows the temperature of the sand and chips sample during frying process at different frying time and temperature. It can be observed from the figure that the changes in temperature of the sand and chips had a similar pattern since the sand, as the heat transfer media, increased its temperature faster than the chips in a short time due to the dimension of the chips that were small and thin.

During frying, the chips received the heat from the sand starting from the surface and moved to the internal part of the chips in three stages: the increase of the chips' temperature, the constant condition of the chips' temperature, and a further increase of the chips' temperature before it constantly went again. The first stage was when the chips' temperature increased due to the direct contact between the hot sand and the chips. At this stage, the temperature of the internal part of the chips increased rapidly. After that, the second stage happened where the increase of temperature slowed down due to the remaining water that started to move from the internal part to the surface of the chips. Simultaneously, further, evaporation took place. Next, the third stage was characterized by the temperature of the internal part of the chips that started to get constant. At this stage, the actual cooking of the chips occurred before it was finally stopped at the designated frying time.

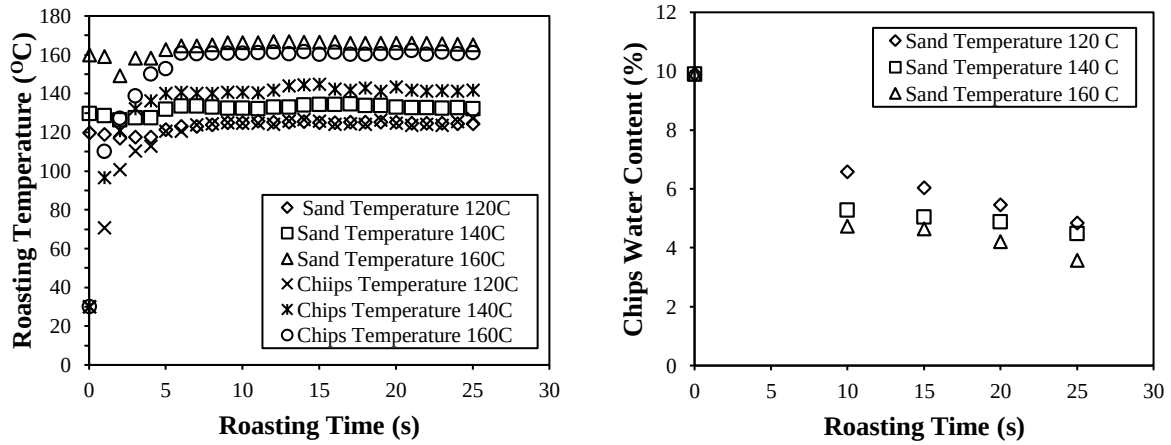

Figure 1. The temperature profile of hot sand (a) and a decrease of moisture content (b) of chips at different frying time and temperature

Figure 1b shows that at the start of the frying, the heat was used to increase the surface temperature before moving to the internal part of the chips. At this condition, water evaporation started from the internal part of the chips moving towards the surface due to the difference in water mass concentration at the surface of the chips that were lower compared to that of the internal of the chips. Therefore, water at the surface evaporated faster due to the direct contact with the hot sand.

These results were in accordance to the report from Garayo [10] who stated that during frying, a decrease of the moisture content of chips took place exponentially following the direction towards the very low moisture content of the sand (0%). The decrease occurred in three stages based on the frying time.

3.2. Simultaneous heat transfer and water evaporation during hot sand frying of chips

Heat transfer and water evaporation co-occurred during hot sand frying of chips at different frying time and temperatures as shown in Figure 2a and 2b. The figures show that when chips were put in the hot sand, the temperature of the chips' surface increased rapidly getting near to the temperature of the sand. Simultaneously, water content within the chips evaporated and caused the surface of the chips to get dry and harden. This condition shows that heat transfer always involves water evaporation.

Furthermore, heat that causes a change of a product's temperature is called sensible heat. When the product reaches boiling temperature, it will go to the state where the temperature will remain constant until all water gets evaporated. Next, the process will continue with the increasing temperature of the product nearing to the frying temperature [11].

During the hot sand frying process of chips, heat transfer started from the hot sand to the surface of the chips and gradually reached the internal part of the chips. Meanwhile, the mass transfer occurred when the moisture content of the chips moves outward to the surface of the chips. Both phenomena happened simultaneously; therefore they were both needed to be studied concurrently. These results showed that frying temperature affected the changes in physical and mechanical characteristics of chips. Similarly, Moreira [12] reported that during frying of chips, simultaneous transfer of heat and mass took place. In this study, mass transfer involved the movement of the moisture content of the chips, since the frying used hot sand as heat transfer media. Heat transfer occurred through temperature changes, while the mass transfer was represented in the decrease of the product's moisture content.

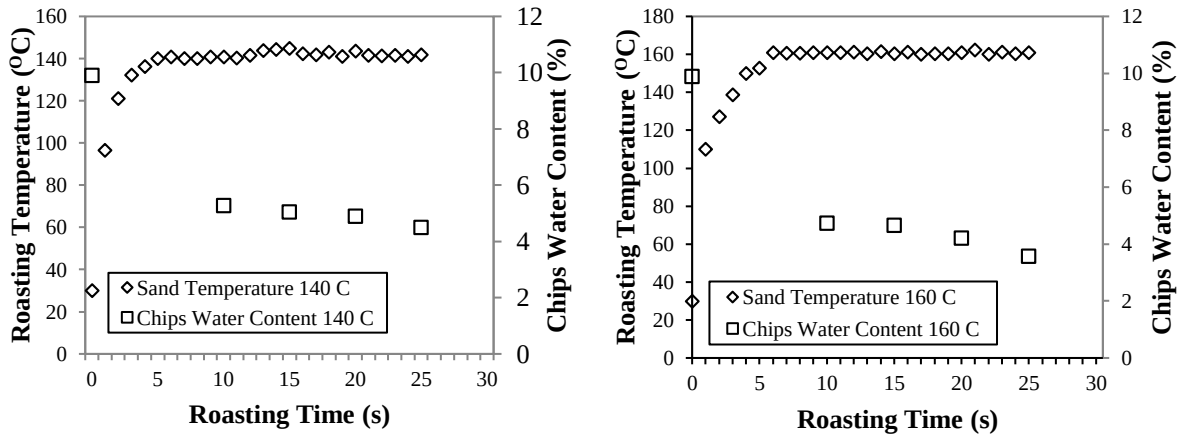

Figure 2. Heat transfer and moisture evaporation of chips during frying at (a) 140ºC and (b) 160ºC

According to Figure 2a and 2b, it can be seen that moisture evaporation was affected by frying temperature. The higher the frying temperature, the faster the moisture evaporation; while the lower the frying temperature, the slower the moisture evaporation. It was because, at higher frying temperature, the evaporation of free water content in chips was faster and thus, causing the chips to get dry faster. Faster moisture evaporation that took place at higher frying temperature caused the heat energy to enter the chips faster as compared to frying at a lower temperature where chips got cooked slower.

Results of this study supported the theory from that explained that at a lower temperature, cooking takes longer time. On the other hand, a higher cooking temperature caused a faster cooking process. According to Fellow [13], heat transfer that happened in deep fat frying was convectional heat transfer from hot oil to the surface of the fried product. Its relevant to the process that takes place in hot sand frying, where products were immersed in the sand. In this process, heat transfer happens conductively where energy is transferred from hot area to the colder area. Conductive heat transfer takes place in the material, without the movement of the media

3.3. Changes in texture, moisture evaporation and a decrease of carbohydrate content during hot sand frying of chips

Figure 3 shows that there was a correlation between change of hardness as a function of moisture evaporation and a decrease of the carbohydrate content of chips. When the moisture content was not stable yet, the change of hardness was small. However, when the moisture content started to be constant, there was a large increase in change of hardness. This condition shows that change of hardness correlates with the evaporation of free water from the chips.

Similarly, the phenomenon in vacuum frying, free water on the surface of the chips evaporated first followed by the water from within the structure of the chip, thus causing the chips to shrink. After most of the free water was evaporated, the surface of the chips started to harden leading the formation of pressurized water vapor in the chips that come from the leftover water that was trapped in the internal part of the chips. This pressure then formed air sack that caused the chips to expand and the texture changed from soft to hard and crispy [14].

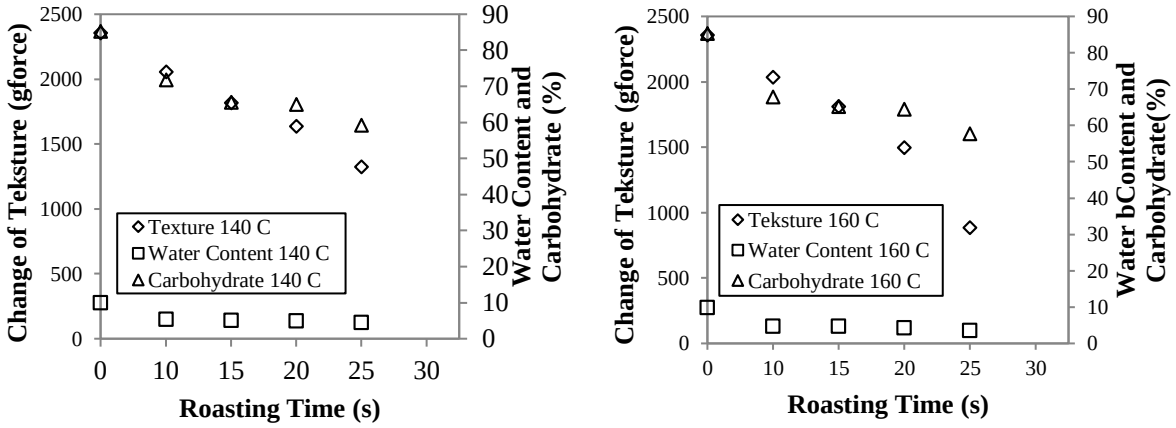

Figure 3. Change of texture, moisture evaporation, and a decrease of carbohydrate content in chips at frying temperature of (a) 140ºC and (b) 160ºC

The calculation of the change of hardness, the decrease of water content and the decrease of carbohydrate in cracker during frying according to equation (1) solved by multiple regression using a computer program. Based on the result, a mathematical model of change of the hardness caused by water evaporation and decreasing carbohydrate level on cracker during frying was obtained as described in equation (2) as follows:

$$T_{\sigma(Ca,\ Ckb)} = 1{,}00\ C_{ca}^{0,85}\ C_{kt}^{0,11} \tag{2}$$

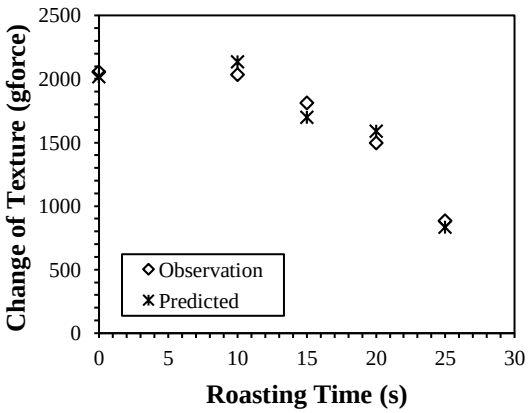

Figure 4. Observation values vs. Predicted values of chips' texture during hot sand frying

The hardness of chips during hot sand frying that was calculated based on the equation developed is shown in Figure 4. The figure shows that calculated values were almost similar to observed values. Statistical analysis also showed that a decrease of moisture and carbohydrate content significantly affected the texture quality of chips ($p < 0.01$). Moisture evaporation and change of carbohydrate content had 50% and 65% effect on chips quality, respectively. Meanwhile, when combined, they contributed to 64.5% of the changes in the chips' texture.

4. Conclusions

Based on the results collected, it can be concluded that during hot sand frying of chips, heat and mass transfer occurred simultaneously causing changes in the chips' texture. The chips' texture was affected by the rate of moisture evaporation and changes in the carbohydrate content of the chips. The point where the chips' texture changed to be crispy occurred when the evaporation of free water in the chips was not constant yet, which was at moisture content higher than 5% (wet basis) and carbohydrate content higher than 70%. However, after the moisture evaporation reached a constant condition at moisture content lower than 5% and carbohydrate content lower than 70%, there was an increase in hardness of the chips that went through the end of the frying process. Statistical analysis showed that the decrease of moisture content and carbohydrate content significantly affected the texture of the chips ($p < 0.01$). Moisture evaporation and change of carbohydrate content each contribute to 50% and 65% of the changes of the chips' texture. Meanwhile, when calculated as a combined effect, both factors explained 64.5% of the change in the chips' texture. Therefore, the model that was developed could be used to predict the change in the chips' texture as a function of moisture evaporation and a decrease of carbohydrate content in chips during hot sand frying.

References

[1] G. R. Takeoka, G. H. Full, and L. T. Dao, "Effect of heating on the characteristics and chemical composition of selected frying oils and fats," *J. Agric. Food Chem.*, vol. 45, no. 8, pp. 3244–3249, 1997.

[2] F. J. Lujan-Acosta and R. G. Moreira, "Relationship between tortilla chips microstructure and oil reduction," *Cereal Chem. J.*, vol. 74, no. 3, pp. 216–223, 1996.

[3] R. Yamsaengsung and R. G. Moreira, "Modeling the transport phenomena and structural changes during deep fat frying: Part I: Model development," *J. Food Eng.*, vol. 53, no. 1, pp. 1–10, 2002.

[4] R. G. Math, V. Velu, A. Nagender, and D. G. Rao, "Effect of frying conditions on moisture, fat, and density of papad," *J. Food Eng.*, vol. 64, no. 4, pp. 429–434, 2004.

[5] S. Whitaker, "Simultaneous heat, mass, and momentum transfer in porous media: a theory of drying," in *Advances in heat transfer*, vol. 13, Elsevier, 1977, pp. 119–203.

[6] M. C. Asensio, "Transport phenomena during drying of deformable, hygroscopic porous media: Fundamentals and applications." Texas A & M University, 2000.

[7] S. A. Matz, "Food texture.," *Food texture.*, 1962.

[8] F. Pedreschi and P. Moyano, "Effect of pre-drying on texture and oil uptake of potato chips," *LWT-Food Sci. Technol.*, vol. 38, no. 6, pp. 599–604, 2005.

[9] A. S. Szczesniak, "Classification of Textural Characteristics a," *J. Food Sci.*, vol. 28, no. 4, pp. 385–389, 1963.

[10] J. Garayo and R. Moreira, "Vacuum frying of potato chips," *J. Food Eng.*, vol. 55, no. 2, pp. 181–191, 2002.

[11] K. J. Chua, A. S. Mujumdar, M. N. A. Hawlader, S. K. Chou, and J. C. Ho, "Convective drying of agricultural products. Effect of continuous and stepwise change in drying air temperature," *Dry. Technol.*, vol. 19, no. 8, pp. 1949–1960, 2001.

[12] R. Moreira, M. E. Castell-Perez, and M. A. Barrufet, "Deep fat frying." 2004.

[13] P. J. Fellows, *Food processing technology: principles and practice*. Elsevier, 2009.

[14] L. Chunmei, L. Yandong, and W. Zongli, "Study on Vacuum Low-Temperature Frying Technology and Equipment Application for Fruit & Vegetable Chips [J]," *J. Agric. Mech. Res.*, vol. 9, p. 57, 2010.